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A stand-alone hydrogen photovoltaic fuel cell hybrid system for efficient renewable energy generation

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ABSTRACT

Today the main concern for World is energy and power age. By and by, out of around 7 billion populaces, just 65-69% approaches power. Essentially to carry the populaces into the office of power access however much as could be expected inside the restricted assets, we have used the regular assets like sun oriented and wind to satisfy this assumption. Utilizing sun based and wind energy in relationship with the power gadgets, we can supply the power to the buyers inside their capacity and we will want to limit the power issue as could really be expected. Hydrogen Photovoltaic Fuel (HPF) cell is the mix of force gadgets which lessens the major sun-oriented emergency of expenses, where expenses are the enormous issue for non-industrial nations. Presently a-days, the coordinated circuits (IC) are entirely solid and modest, to the point that make the conveying and reversing or changing over components simplest than the massive and expensive instruments utilized in the traditional power supply framework. The examination expects that the lattice joining of the environmentally friendly power assets utilizing HPF inverter might cause a colossal comment in satisfying the absence of force use across the world. Solar energy is a rapidly growing resource, already providing 4.5% of electricity in the World and projected to supply up to 35% by 2050. On the other hand, the default model's predictions were far from the actual metered HPF data. For renewability, the simulated renewable energy consumption with modified inputs is 3.9% below of actual metered renewable data while the default model's prediction was more than 52% below actual renewable use. Using PV-HPF hybrid model indices to represent how well a simulated model describes the variability in the measured data; the modified model has achieved accurate renewability results; with a Solar of 10.99 % and Wind of 9.90%, while the hybrid model has a solar of 57.16% and a Wind of 57.20% in renewable energy comparison being performed in MATLAB.

Keywords: Renewable Energy, Solar, Wind, Photovoltaic, Power, Green Energy, Hydrogen Photovoltaic Fuel, Grid.

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1 Introduction

One way in which solar energy reaches end users is through the purchase of bulk electric power systems. In the United States, these are non-profit organizations appointed by the Federal Energy Regulatory Commission (FERC) called Independent System Operators (ISOs). They are responsible for coordinating the flow of energy across the electrical grid, fairly administering electricity markets, facilitating non-market electricity purchase contracts, and planning the power grid to ensure that it can meet demand. They are funded by collecting service fees from market buyers and sellers at the minimum level required to cover costs. Their markets manage 60% of the nation's electricity with the objective of balancing supply and demand for the entire system by allowing individual generators to submit bids detailing the quantity and price at which their resource can supply to the market. Solar energy is a rapidly growing resource, already providing 4.5% of electricity in the US and projected to supply up to 35% by 2050. Relying only on the strength of the solar to power its electricity-generating turbines, solar power has no marginal fuel costs. While there are still operational and maintenance costs, the lack of marginal fuel costs makes solar power highly competitive at the margin with other more established types of generation, such as coal, natural gas, hydropower, and nuclear. Furthermore, it is virtually greenhouse gas emission-free and does not pollute nor consume resources, making it a key technology in decarbonizing the grid and meeting climate goals as mentioned in [1]. Energy is procured from these generators through a least-cost purchasing rule known as the merit order, which accepts energy bids in increasing cost order until demand is met. This energy is then transmitted throughout the grid, reaching homes and businesses throughout the ISO’s territory to meet demand as mentioned in [2]. In this research, I quantify the ability of solar to reduce prices for consumers, asking: how does the quantity of solar generation being bid in competitive electricity markets affect the wholesale price of electricity? Bid in by solar generators at $0.00 marginal cost, solar energy should decrease prices at levels varying by 1) the quantity of solar added to the market, 2) the level of demand, and 3) the marginal costs and quantities of other resources on the market. Assuming perfectly inelastic demand and leaving out the effect of the exit of other firms in the long run, I estimate the impact of increased solar penetration under different quantity, demand, and resource mix scenarios by simulating the market mechanism using historical market data and evaluating the price changes that result. I look specifically for this effect at the day-ahead market administered by the world, which accounts for about 30-40% of the energy procured in this region of 14 million customers as mentioned in [3].

Figure 1. Different renewable energy sources with user-friendly graphics [4]

1.1 Problem statement

To beat the current issues regarding the electric power in World however much as could be expected, this task is worked to meet the issue went with the current assets. To execute the undertaking, the power hardware gadget, for example, three stage HPF (Hydrogen Photovoltaic Fuel) inverter will be carried out in relationship with PV (Photovoltaic), diodes, capacitors and so forth The normal asset usage interaction like Solar turbine or Solar board comprises the variable DC power is changed over to fixed DC through a converter and the proper DC power is then modified to AC power through a three stage inverter went with HPF and the result AC is incorporated to the matrix through the synchronizer.

- **Energy security:** It decreases or kills the need of imported energy sources which censures to the expanded energy security.
- **Enhanced dependability:** Reducing the requirement for imported fuel and drawing some age nearer to the heaps they serve, can further develop energy framework unwavering quality.
- **Financial openings:** By utilizing the more energy sources which isn't related with the market changes, we can decrease the drawn-out energy expenses for the buyer.
- **Reduce the expense:** The minimal expense of the power gadgets decreases a measure of cost rather than three stage AC transmission framework.

- **Easy execution:** The execution of this task is solid and can be handily completed from one station to other.

1.2 Aim of study

The research goes through various research papers and articles performed on sensitivity analyses of building renewable energy simulation to narrow down the number of most significant input parameters for renewable energy simulation. Based on the literature review, the most influential input parameters are: temperature and humidity set-points and setbacks, lighting density and schedule, equipment density and schedule, occupancy density and schedule and ventilation rate. The present study uses MATLAB which is an interface of the famous energy calculation engine, Energy Plus (MATLAB, R2019a). MATLAB offers a user-friendly three-dimensional interface that allows users to easily create building zones with correct geometry and orientation, and easily specify the details of the enclosure properties and the internal loads. One of the ways that nations can negate this impending disaster is through subsidies to renewable energy consumption. In this research I aim to test what, if any, subsidies provided by the world would have the largest impact on the consumption of renewable energy in terms of green energy using HPF and PV solar system. Having this knowledge, I am to study if reverting fossil fuel subsidies which are harmful to the environment towards renewable energy subsidies would be economically feasible using the PV solar system and HPF. The combination of price drops and large-scale implementation improvements means that countries can now start rolling out renewable energy to the general population for low enough prices that, even without government subsidies, renewable energy technology will be able to compete with PV solar system replacing the old fossil fuels. In a world that focused on climate change, one nation sticks out as a country with the ability to fix this problem on a large scale. However, the focus of the research would be oriented in the solar power simulation generation for green renewable energy using the HPF and PV.

2 Background

Building energy simulation software's are complex programs that contain hundreds of parameters. Simplifying the simulation by sensitivity analysis has been one of the focuses of many researchers. Researcher in [5] provided introduction to renewable energy that time consumed in modeling a good and accurate energy model is one of the reasons for its discrete use in engineering firms, therefore, simplifying the simulation method by analysis of the influence of input parameters may provide an easier and faster way to model accurately. Researcher in [6] talks about that there is a need for high accuracy in practical energy calculations, but to further facilitate this high accuracy practically, it is important to provide simpler but robust methods. Researchers in [7] mentions that when performing energy simulations, some input parameters have more influence on the results than others and more attention should be put on these parameters. Finally, in one of the latest publications, [8] mentions that there is a growing interest sensitivity analysis and uncertainty analysis in building energy simulation, especially for retrofitting projects. While many have estimated the effects of solar generation on electricity market prices, none have simulated the direct price impact of additional units of solar as a counterfactual to historical data. Below, I discuss existing estimations of solar impact on prices, the effect of the energy mix on this impact, attempts to structurally model the supply and demand curves in these markets, and potential engineering constraints that may dampen the price suppressant effect of solar as mentioned in [9]. The impact of solar and other renewable resource generation on electricity prices is known as the merit order effect, and has been estimated by a number of different re- searchers with data from markets around the world.

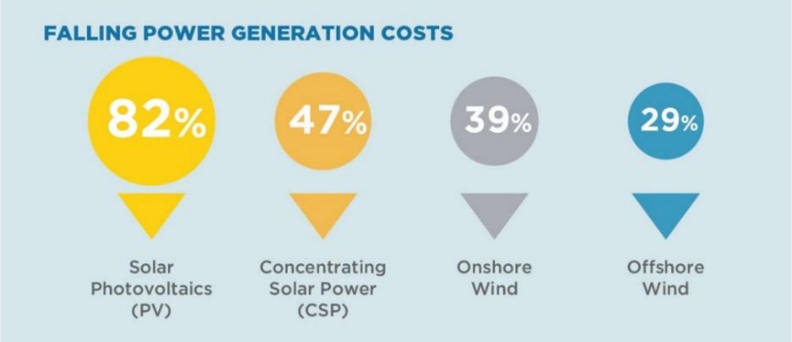


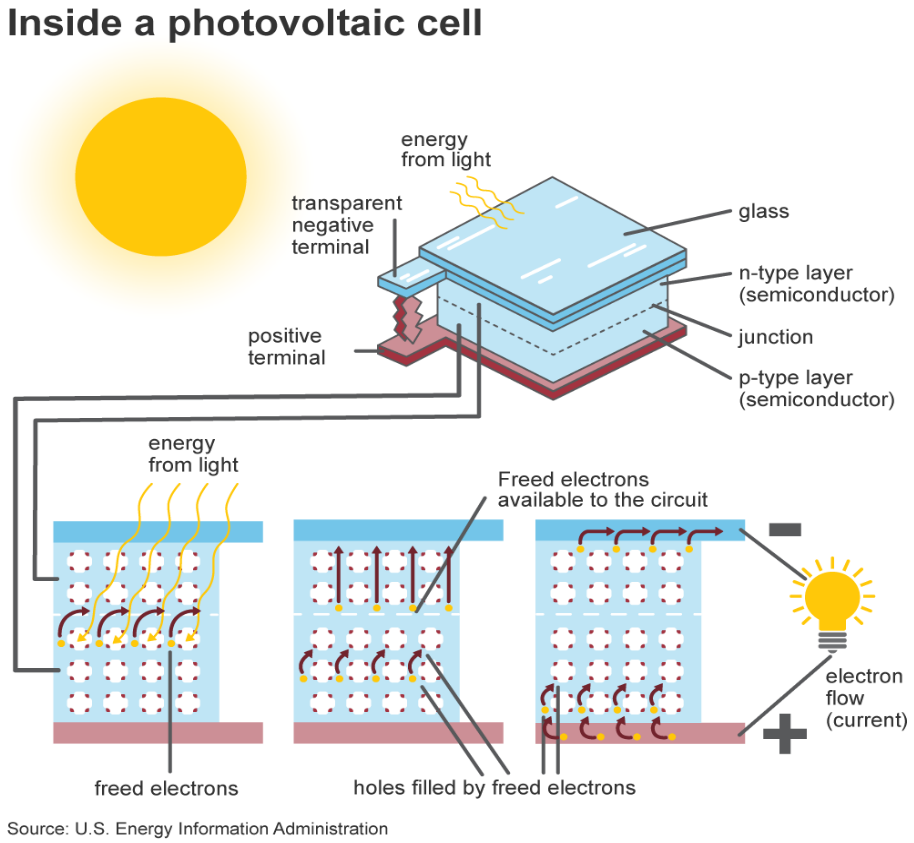
Figure 2. Renewable Energy Costs Declined Rapidly Over the Last 10 years [9]

Researchers in [10] demonstrated the effect of solar on spot prices in the renewable energy market (which is far more solar-saturated than ISO with solar comprising 20% of generating capacity). Using solar power forecasts as a proxy for generation magnitude, they showed a shift in the mean price towards zero as solar penetration increased, with 2% of periods of over 40% solar penetration demonstrating a spot price of $0.00. Researchers in [11] showed that the impact of solar energy on prices via the merit order effect is more strongly negative during the day than night, depends on the generation mix and flexibility of conventional capacity, and has decreased over time in [12] use a regression model similar to the one I use in estimating the relative effects of different resources on the clearing price; their model controls for the effects of demand, natural gas price, and time-based fixed effects to show the price decreasing effects of additional wind and solar generation on the Italian power market. The merit order effect varies by level of solar penetration, accuracy of forecast, and whether curtailment (when the system operator forces a resource to stop contributing to system supply in the case of overproduction) is allowed in a market. Researchers in [13] show that volatility increases, and price decreases as solar penetration increases, with more volatility appearing at more granular market timescales (e.g. five minute vs. hourly). Though I do not consider forecast accuracy or curtailment (as these factors add complexity beyond the scope of this research), I do expand upon the effect of different levels of natural gas supply on wind's effect on price as they suggest should be explored in future research.

Table 1. Frequency of recommendation for each prime parameter in the reviewed literature

PARAMETER		**FREQUENCY OF RECOMMENDATIONS IN THE LITERATURE**
Solar Photovoltaic (PV)	Solar Shading Coefficient	7
	Green Energy Generation	6
	PV Cell Accounting	7
	PV Infiltration	1
	Occupancy	3
Hydrogen Photovoltaic Fuel (HPF)	Solar Equipment	9
	HPF Ratio	12
	Occupancy	8
Onshore Wind	Onshore Wind Equipment	9
	Wind Speed	10
	Fan efficiency & pressure	8
Offshore Wind	Offshore Wind Equipment	8
	Temperature set-points	13
	Temperature set-backs	13
	Fan efficiency & pressure	7
HVAC Plant [14]	Green Generation	6
	HVAC temperature	1
	Boiler Efficiency	4
	Pump Efficiency	4
	Hot Water Temperature	2

To choose the most influential parameters, the parameter should have a minimum number of 9 recommendations, which makes 50% of the research papers, to be considered an influential parameter. From Table 1, the most influential input parameters that were most frequently recommended with 14 recommendations or more are: temperature set-points and setbacks (highest frequency), lighting density and schedule, equipment density and schedule. The nature of lighting and equipment schedules is directly related to the occupants' behavior since occupants are the ones using the lighting and equipment. Therefore, occupancy schedule is as important as an input parameter to be modified as the lighting and equipment schedules as described in [15]. In addition, all of literatures reviewed are performed on offices and university buildings; therefore, ventilation was not a major parameter in these spaces. However, a substantial energy consumer in laboratories is caused by fume-hoods and the air-quality requirements, therefore, ventilation rates are very important for generation spaces as described in [16]. Therefore, the primary input parameters that this research will focus on and vary their values to improve the accuracy of the energy simulations for the case-studies are: temperature set-points and setbacks, lighting density and schedule, equipment density and schedule, occupancy schedule, and ventilation rates as described in [17]. The price effects of additional solar generation depend on the existing energy mix. Researchers in [18] show that increased solar penetration in World has little impact on average prices because of the prevalence of imported gas generation from the world, which comprises 48% of supply and generally function as the price setting marginal fuel. Researchers in [19] note that increasing solar penetration has its greatest effect on the generation mix via reducing gas and oil generation, the most common marginal fuel on the bid curve. However, the use of these resources increases as the accuracy of solar forecast decreases; in the case that solar generation falls short of forecasted levels, gas and oil are often called upon to meet the gap as fast-ramping generators that can quickly activate at relatively low cost. Following this literature in [20-22], I later take the level of gas generation into account when estimating the impact of additional solar generation in my simulation.


Inside a photovoltaic cell

Source: U.S. Energy Information Administration

Figure 3. Renewable energy capacity in photovoltaic cells being stored directly from sunlight [20]

3 Methodology

The merit order procurement mechanism is the process used by the ISO to accept the supply needed to meet demand at least cost for green energy generation using the PV and HPF. It minimizes the cost of procuring electricity by accepting bids of price and quantity in least cost order until demand is met. This can be expressed as follows: The merit order holds for the vast majority of hours, though it is occasionally overridden if other grid constraints must be met. For example, if demand sharply spikes between hours, the next cheapest resource may be ignored in favor of a different resource that can activate more quickly to provide electricity in time for the next hour. Another case is of transmission constraints: the next cheapest resource may be ignored if it is located in a place on the grid that is not capable of providing electricity to meet demand appearing in a different part of the grid due to transmission constraints (when electrical lines are physically unable to transmit electricity between two locations). However, cases like these are non-dominant and unpredictable with the data available; thus, I assume in my market simulation that such constraints do not occur. Future work should relax this assumption, as solar generation tends to take place in areas farther away from the sources of greatest demand (i.e. offshore or in less populated rural areas), suggesting there may be a correlation between solar generation and increased overriding of the merit order unless additional transmission infrastructure is built to counteract this potential effect.

Pertaining the HPF for generating the renewable energy.

$$CSP(t) = R_i(t) + Ld_i(t) + v_c(t)$$

$$\frac{d_i(t)}{dt} = -\frac{R_i(t)}{L} - \frac{v_c(t)}{L} + \frac{v_i(t)}{L}$$

The generation across the whole generating process is given by -

$$v_c(t) = \frac{1}{c}\int i\,(t)dt$$

The HPF equation considered with respect to time.

$$\frac{dv_c(t)}{dt} = \frac{i(t)}{c}$$

State vector, X = $\begin{bmatrix} v(t) \\ v_c(t) \end{bmatrix}$

State Vector Differential, $\dot{X} = \begin{bmatrix} \frac{di(t)}{dt} \\ \frac{dv_c(t)}{dt} \end{bmatrix}$

$$\dot{X} = \begin{bmatrix} \frac{di(t)}{dt} \\ \frac{dv_c(t)}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & -\frac{1}{L} \\ \frac{1}{c} & 0 \end{bmatrix} \begin{bmatrix} i(t) \\ v_c(t) \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \begin{bmatrix} v_i(t) \end{bmatrix}$$

$$Y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} i(t) \\ v_c(t) \end{bmatrix}$$

where,

$$A = \begin{bmatrix} -\frac{R}{L} & -\frac{1}{L} \\ \frac{1}{c} & 0 \end{bmatrix} \; B = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \; C = \begin{bmatrix} 0 & 1 \end{bmatrix} \text{ and } D = \begin{bmatrix} 0 \end{bmatrix}$$

Hybrid PV and HPF Model Equation:

$$CSP = \frac{b_0}{s^n + U_1(t) - 1s^{n-1} + \cdots . + k_1 s + U_1(t)}$$

Repositioning the above equation as

$$(s^n + U_1(t)\, s^{n-1} + \cdots .. + a_0 B(s) = b_0 M(s))$$

Apply inverse Laplace transform on both sides of hybrid PV and HPF equation model.

$$\frac{d^n y(t)}{dt^n} + k_{n-1}\frac{d^{n-1}y(t)}{dt^{n-1}} + \ldots + k\frac{dy(t)}{dt} + k_0 y(t) = b_0 u(t)$$

At its most simplified, the supply curve formed by the ordering of bids forms an exponential curve, with clearing price corresponding to the intersection of supply with a fixed level of demand. The drivers of the exponential shape of the supply curve and the magnitude of demand are discussed below.

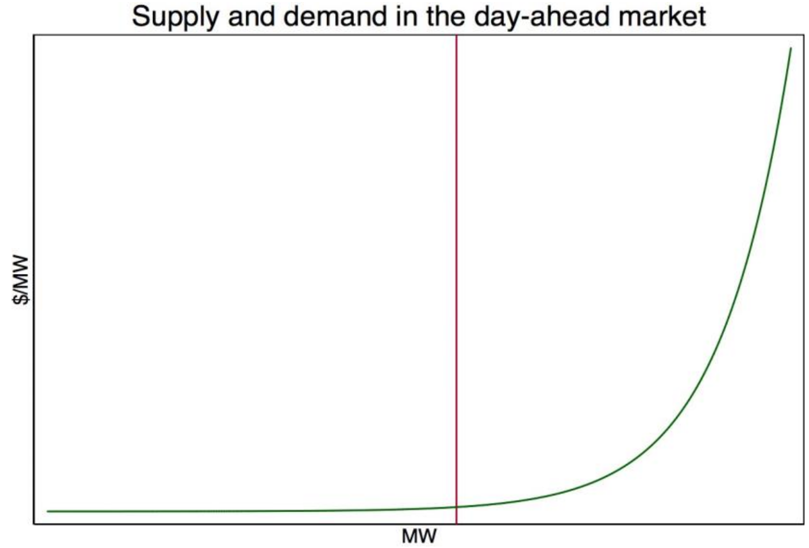


Figure 4. A schematic representation of supply and demand

In the short run, demand is determined largely independently of supply and price, driven by factors such as the season, time of day, day of the week, weather, and efficiency of electrical appliances and buildings. It is relatively inelastic to changes in price since there are often no substitutes for electrical power. This changes slightly in the long run, when consumers can make more long-term changes in their consumption levels in response to price (such as buying more energy-efficient fixtures, improving building insulation). For example, elasticity of demand of residential electricity price in World is estimated to be about -0.192 in the short run, and -0.325 in the long run. Economic growth has been a large driving factor in the past, but this effect has waned as growth in GDP has increasingly decoupled from growth in electricity demand.

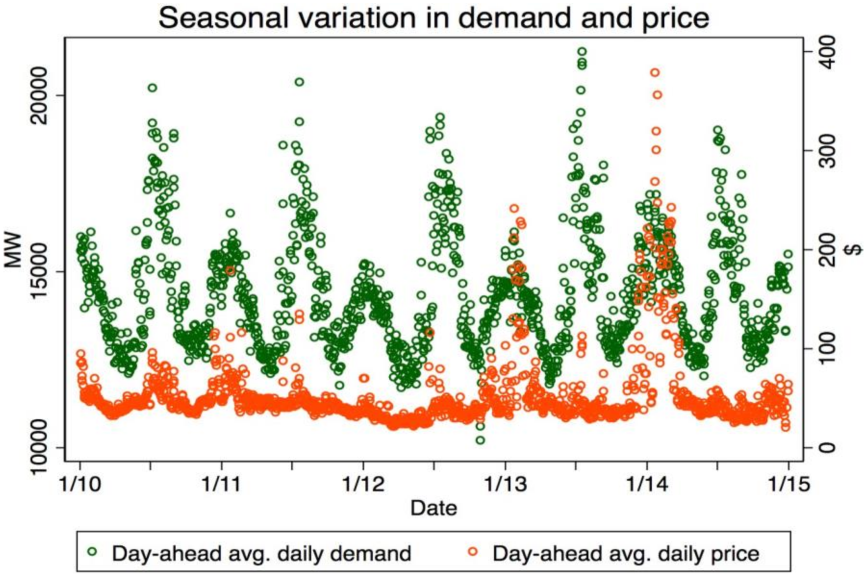


Figure 5. Demand and price tend to spike concurrently

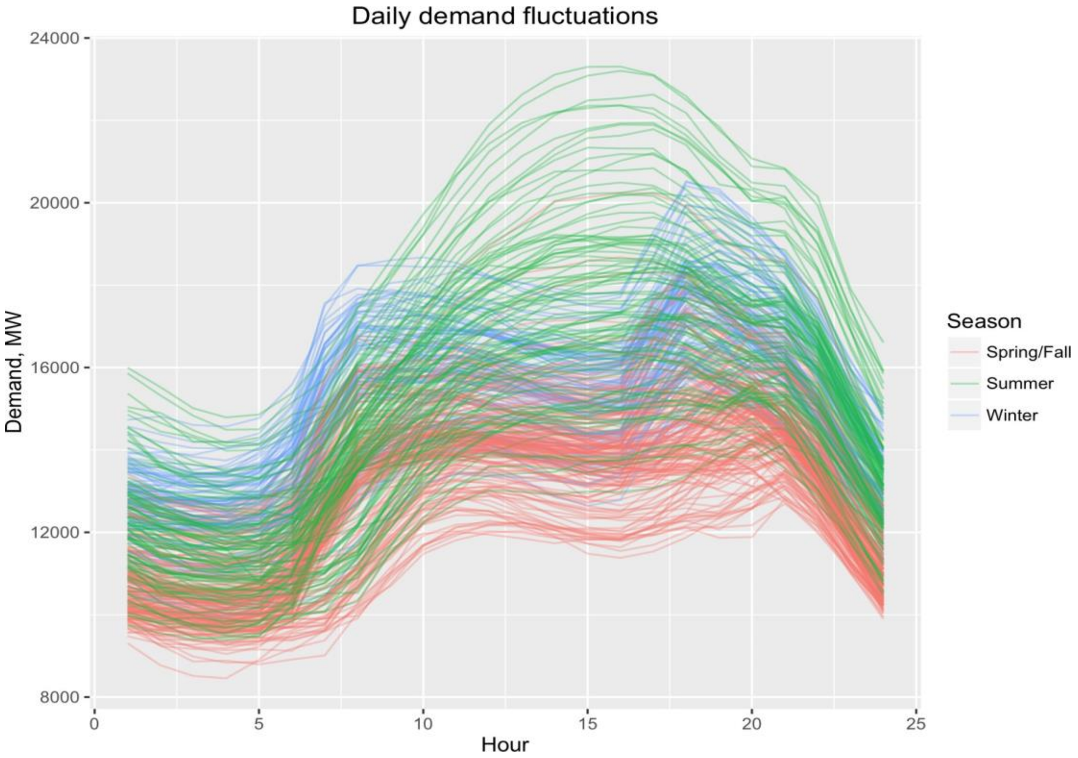


Figure 6. Daily demand patterns vary seasonally

Putting the bids of all generators in increasing price order results in the construction of the bid curve, which provides a useful visual representation of price variation in a market. The exponential behavior of the bid curve, as constructed from day-ahead offer data taken from ISO's system on January 1st, 2020 at 9 AM. This exponential shape is the result of 1) bids from rarely-activated, more expensive reserve generators and 2) expensive higher segment bids offered by generators with marginal costs varying by quantity supplied. The red line in figure 7 indicates the demand of the hour, which is 13,847.9 MW and crosses with the supply curve at $174.61, the clearing price. All generators bidding at or below this price will clear demand and be paid this amount for each MW bid during the hour, while generators above are not activated. This exponential shape explains the appearance of price spikes during hours of abnormally high demand, since generators at the far right of the curve exhibit significantly higher costs. It also suggests that prices remain relatively stable when demand remains between 10,000-20,000 MW (which it generally does), as the slope of that middle range is relatively gradual.

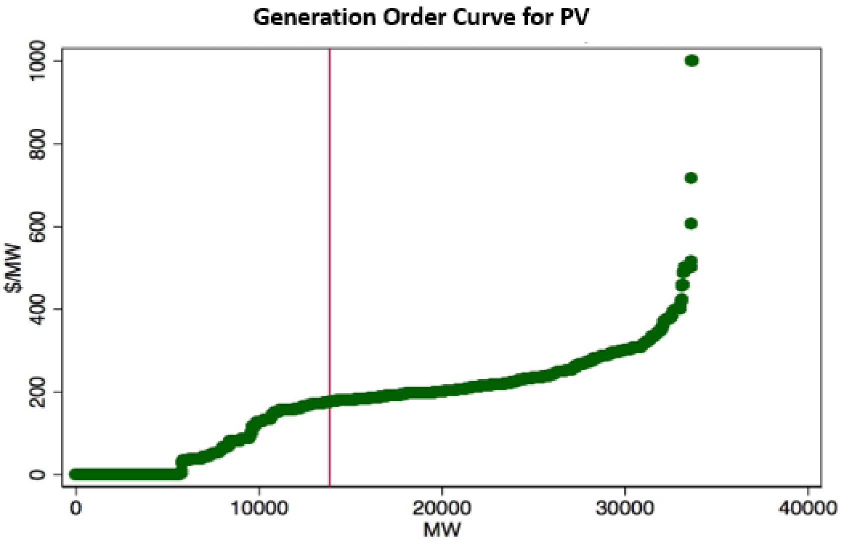


Figure 7. The bid curve displays an exponential shape for PV generation

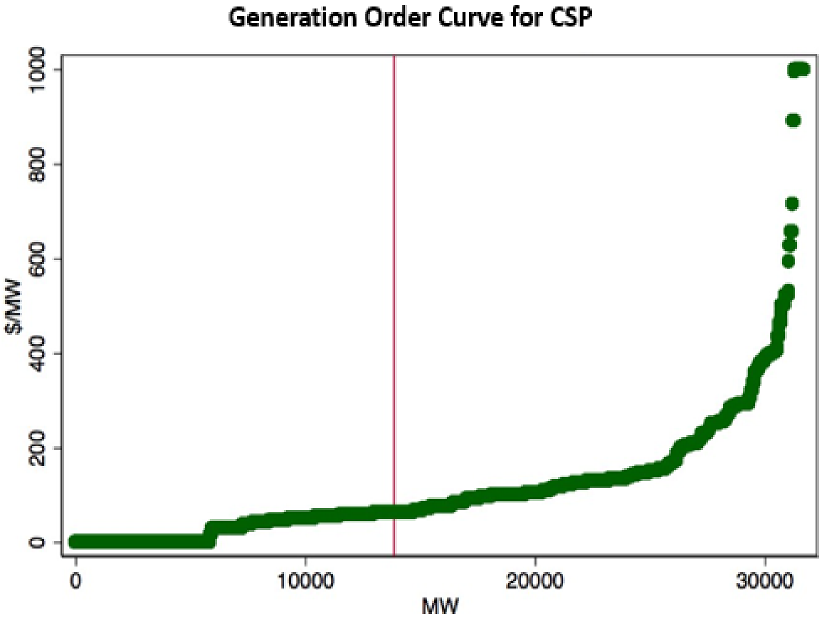


Figure 8. The slope of the bid curve for HPF generation is determined by generator's marginal costs

A look at the same day and hour in 2020 shows that the resource mix has changed over the years. This earlier date displays a more gradual slope upwards where the 2020 date shows a sharper increase between 6,000-10,000 MW. This smoother curve may have been due to the presence of more nuclear generation, which provides relatively low to no marginal cost electricity, and volatility in the price of natural gas, which directly alters marginal costs for generators and adjusts the slope of the gas-dominated middle section of the curve.

4 Results

It is interesting to note that temperature is a large contributor to the amount of supply available to the system; a likely explanation for this trend is the cost of cooling most generation plants (particularly coal, oil, natural gas, and nuclear). In warm weather, it becomes costlier to generate the same amount of energy because of increased cooling costs from the effects of ambient heat, whereas the opposite effect occurs for cooler temperatures. To determine the clearing prices that would have resulted from adding various amounts of solar generation into historical data hours, I run a simulation in MALAB which takes hourly data from ISO on day-ahead market energy offers and demand, constructs supply curves from the energy offers, and calculates clearing prices based on the intersection of the supply curve with the fixed hourly demand, as seen in the representation above. The original clearing price for the hour is first calculated by intersecting demand with the original set of energy offers. Then, to calculate the prices that result from additional solar generation, I modify the supply curves of each hour to add solar bids in increments of 100 MW (greater granularity makes the datasets too large to process without providing much additional information) and then re-solve for the supply-demand intersection to find the new clearing prices at each of these increments. Re-solving problem after inserting an additional solar bid is equivalent to decreasing demand: shifting the entire bid curve to the right by inserting 1 MW of solar at the bottom of the merit order is equivalent to shifting demand down by 1 MW in terms of the clearing price resulting from the new intersection of supply and demand. Thus, I decrement demand rather than resolving the problem at each step with a new supply curve to reduce computational complexity. It should be noted that the clearing prices calculated from the intersection of cleared demand and the bid curves constructed from hourly bidding data do not exactly match up with actual hourly clearing prices. This can be explained by relaxing our earlier assumption that the merit order is never violated, which does not hold true in the case that other grid constraints, such as transmission constraints, come into play.

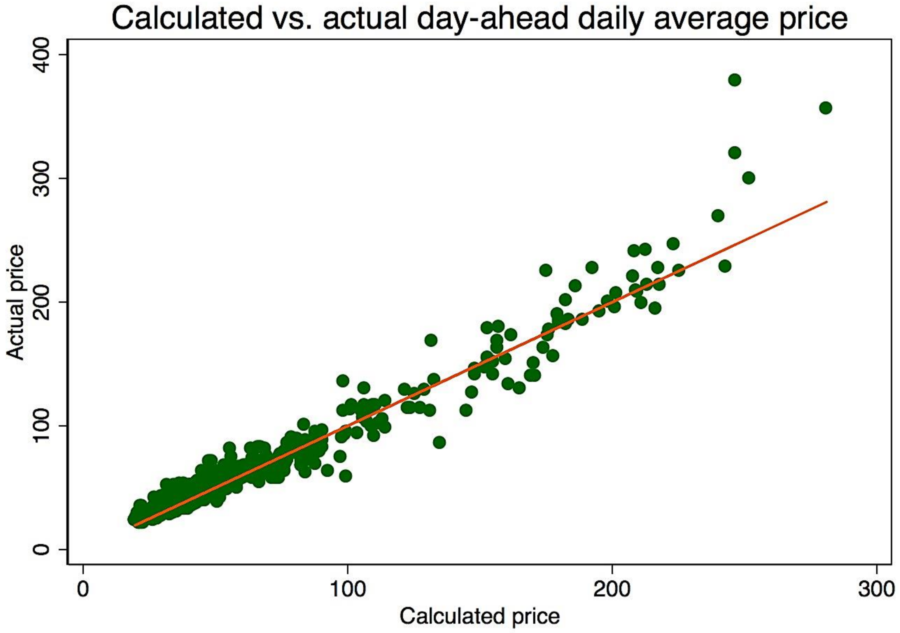


Figure 9. The difference between the calculated and actual price differs the most during price spikes The orange line represents a 1-to-1 relationship.

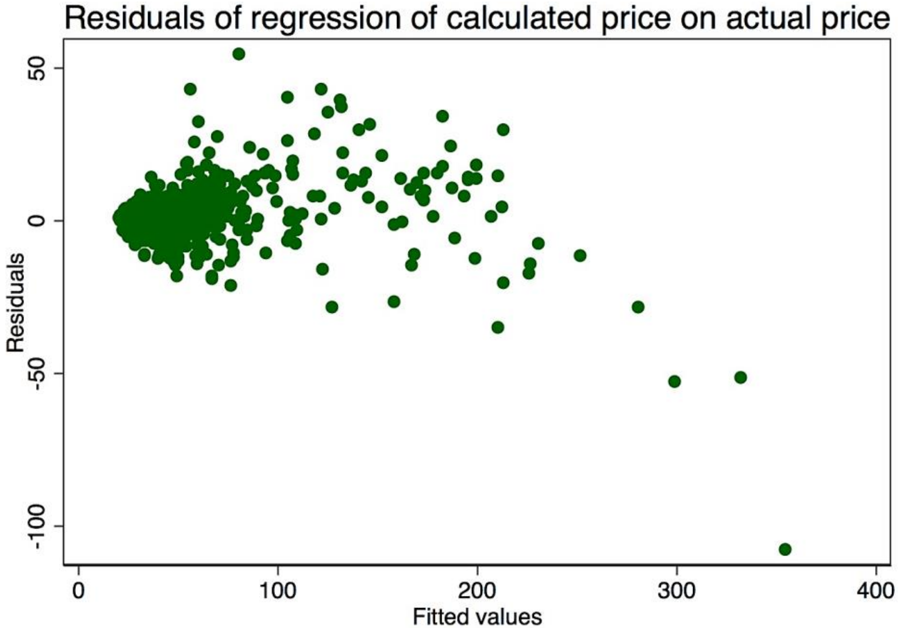


Figure 10. Calculated price skews too low as actual price increases

Using PV-HPF indices to represent how well a simulated model describes the variability in the measured data; the modified model has achieved accurate renewability results; with a Solar of 10.99 % and Wind of 9.90%, while the default model has a solar of 57.16% and a Wind of 57.20% in renewable energy comparison. For renewable energy, the modified model achieved a lower accuracy in heating energy than in renewability; however, it is still a substantial improvement over the default model. The simulated renewable energy consumption with modified inputs is within 7.95% above actual metered data while the default model's prediction was more than 58.8% below actual thermal use. Using Micro-Grid line indices for the default model are Solar of 33.97% and Wind of 27.30 %, while the proposed model has a Solar of 83.18% and a Wind of 64.53%.

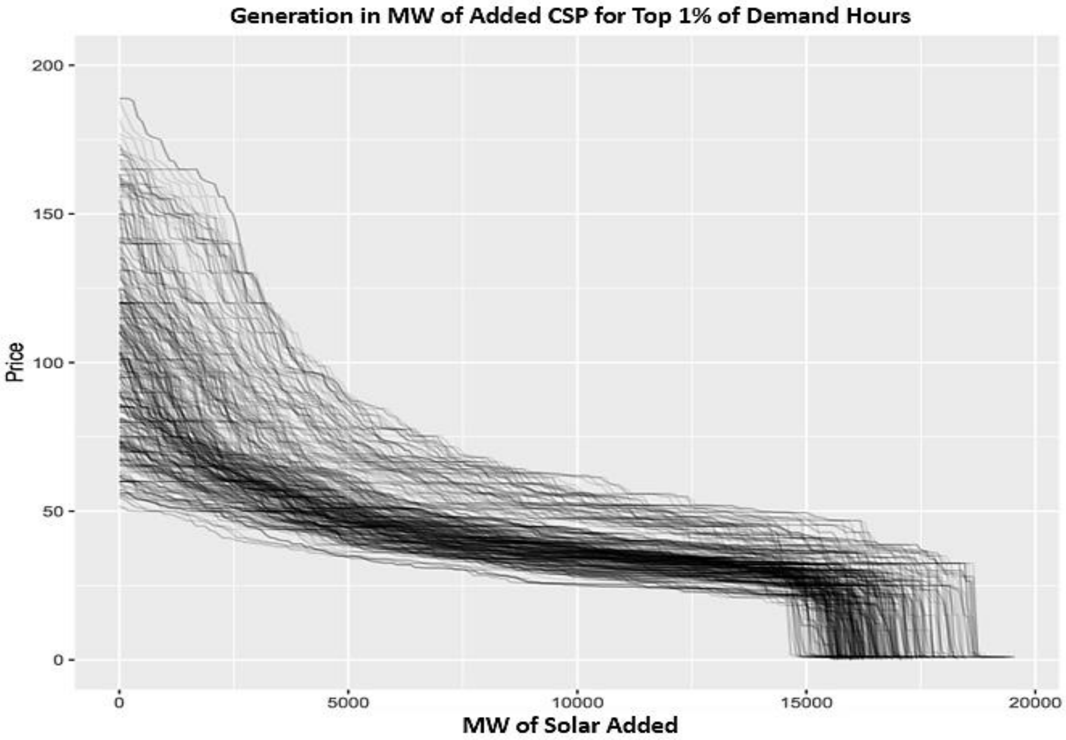


Figure 11. Price decreases sharply with additional solar during high demand hours

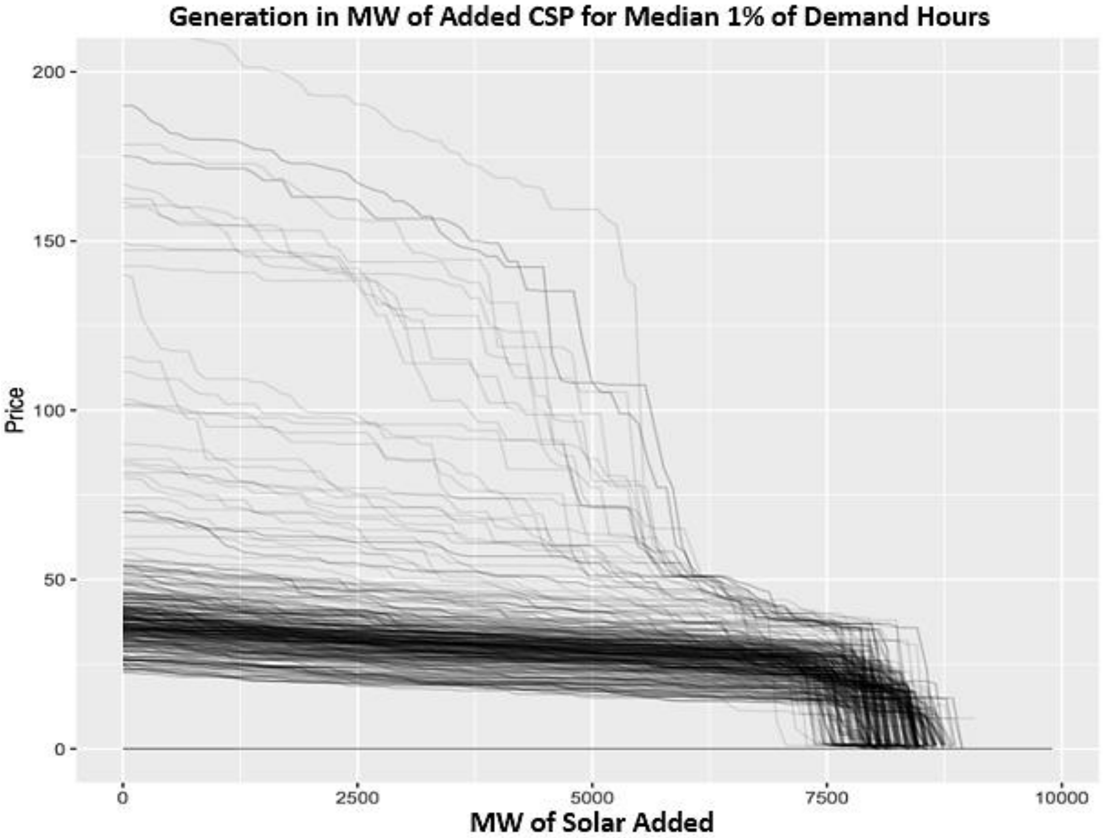


Figure 12: The gradual slope of the curve reflects the gradual upward slope of the middle of the bid curve, which is dominated by similarly-priced solar generation.

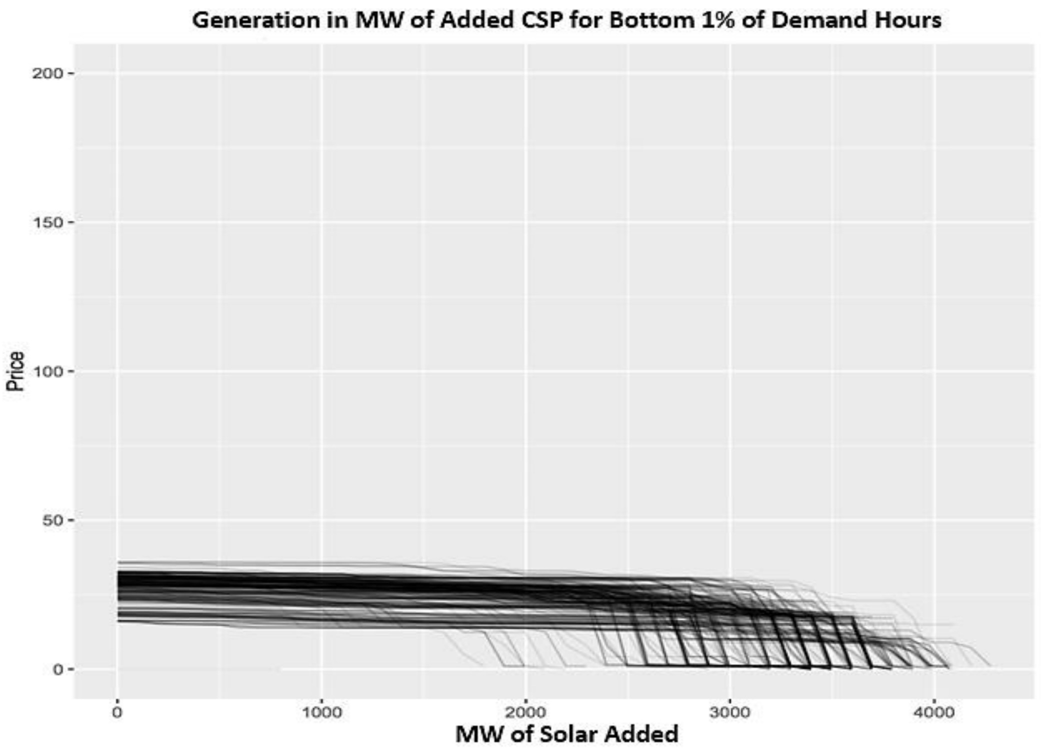


Figure 13. At low demand, price remains steady in the face of additional solar generation

This is calculated by regressing the effect of varying MW of additional solar added to the system Wm (under the quantity segments r = [0, 1500), [1500, 3000), and [3000, 5000)) on net price change ΔPm under different levels of gas penetration g and demand d, the result of which is then multiplied by 100 to give a better sense of the savings in more realistically large increments. This results in coefficients that measure the average effect of an increase in solar among different conditions on the 48 observed hours.

Table 2. Demand and change in price

Demand		**Mean price ($/MW)**	
Bottom 25% (Q1)		$33.339	
Lower middle 25% (Q2)		$43.001	
Upper middle 25% (Q3)		$46.951	
Top 25% (Q4)		$69.940	
Top 5%		$73.029	
Top 1%		$99.404	
Δ in price per 100 MW added, for 0-1,500 MW of additional solar energy			
Demand	**Low Solar (g≤42.1%)**	**Median Solar (4.21%<g≤53.4%)**	**High Solar (g>53.4%)**
Q1	-$0.268	-$0.146	-$0.121
Q2	-$0.366	-$0.218	-$0.188
Q3	-$0.398	-$0.261	-$0.243
Q4	-$0.658	-$0.437	-$0.505
Top 5%	-$1.681	-$0.694	-$0.777
Top 1%	-$1.218†	-$1.218	*-$1.334 (P=0.004)*
Δ in price per 100 MW added, for 1,500-3,000 MW of additional solar energy			
Demand	**Low Solar (g≤42.1%)**	**Median Solar (4.21%<g≤53.4%)**	**High Solar (g>53.4%)**
Q1	-$0.382	-$0.170	-$0.208
Q2	-$0.431	-$0.176	-$0.128
Q3	-$0.368	-$0.206	-$0.173

Q4	-$0.528	-$0.337	-$0.382
Top 5%	-$0.904	-$0.542	-$0.587
Top 1%	-$0.965†	-$0.965	*-$1.036 (P=0.040)*
Δ in price per 100 MW added, for 3,000-5,000 MW of additional solar energy			
Demand	**Low Solar (g≤42.1%)**	**Median Solar (4.21%<g≤53.4%)**	**High Solar (g>53.4%)**
Q1	-$0.725	-$0.491	-$0.433
Q2	-$0.784	-$0.172	-$0.131
Q3	-$0.449	-$0.156	-$0.119
Q4	-$0.519	-$0.238	-$0.258
Top 5%	-$0.689	-$0.364	*-$0.383 (P=0.001)*
Top 1%	-$0.686†	-$0.686	-$0.655 (P=0.138)

† = collinear with the median PV-HPF value

Each one of these coefficients has P=0.00 except for the italicized entries, which have their P-value written beside them. Among these estimations of solar effect on prices at different levels of increased solar, demand, and contribution of gas to total supply, a few trends reveal themselves. First, price change becomes greater at all levels of gas penetration as demand rises for low and medium (≤3,000 MW) additions of solar. Second, the magnitude of price change increases with greater levels of gas penetration for low and medium additions as well. This is likely because gas takes a larger share of supply when both demand and prices are high; high gas share suggests that demand may have cleared at a part of the bid curve where prices display a steeper slope. High additions of 3,000-5,000 MW do not follow these trends, as prices have already fallen down the steepest decline in the bid curve, which is then followed by a relatively flat region of similarly priced gas generators. Results suggest that hours at which the greatest price decreases can be realized are those with a high share of solar generation and high demand, with the most negative coefficient appearing as -$1.334 per 100 MW for penetrations of solar over 53.4% at the top 1% of demand hours. It should be noted that these effects may vary as the generation mix changes. Higher penetrations of solar suggest that a large amount of other highly-priced (and likely higher priced) resources are also being called upon. How often a turbine runs, and the magnitude of its output depends on its location, but the average turbine produces electricity 70-85% of the time, with output depending on solar velocity. More than 1,000 MW of additional solar capacity would need to be built for 1,000 MW to constantly be available on the system.

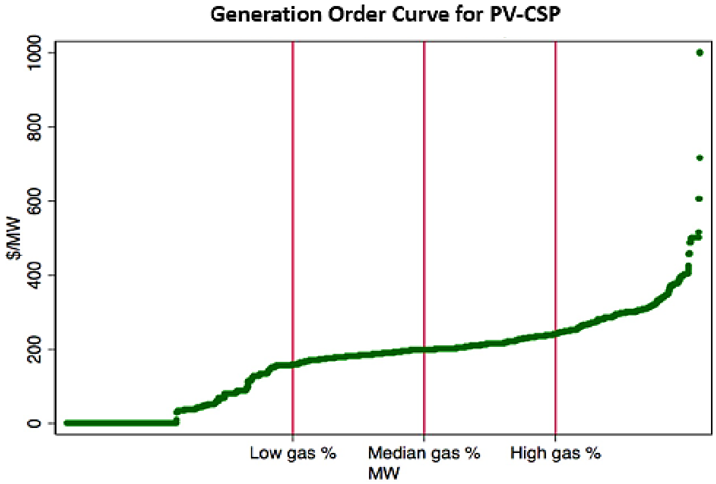


Figure 14. The red lines designate different levels of demand at which PV-HPF generation contributes varying levels of supply

As green generation mix becomes increasingly dominated by solar and natural gas, the bid curve will gradually lose its exponential peak and display more of a logarithmic shape, with a long stretch of $0.00/MW bids followed by a step up to a steady stretch at the price of natural gas generation. In this largely dual-fuel paradigm, prices should remain relatively stable, switching between the two levels of price depending on demand.

5 Discussion

Reading the results of the three case-studies, the modification of the identified influential parameters has a major impact on the energy predictions and produce results that have good agreements with the actual metered data for PV and HPF. Additionally, the research found that the impact of these modifications depends on the percentage the generation spaces occupied from the total area of the renewable energy. Micro-Grid is used to measure the accuracy of the energy models before and after the parameter modification using solar and wind renewable energy generation. Table 3 summarizes the percentage of generation spaces and the renewable energy generation of the models for PV, CWP and HPF.

Table 3. Accuracy measures of the default and modified energy models for different energy sources using renewable energy generation with total energy generation in percentage

Case-study	**Total Generation (%)**	**Phase**	**Simulation-Default**		**Simulation-Modified**	
Photovoltaic (PV)	31%	New Construction	Renewable	Solar= 27.1%	Renewable	Solar= 11.2%
				Wind= 27.8%		Wind= 10.0%
Hydrogen Photovoltaic Fuel (HPF)	55%	Before Renewable energy renovation	Renewable	Solar= 57.2%	Renewable	Solar= 10.9%
				Wind= 57.2%		Wind=9.9%
			Renewable	Heat=83.2%	Renewable	Heat= 33.9%
				Heat= 64.5%		Heat= 27.3%
		After Renewable energy renovation	Renewable	Solar=45.6%	Renewable	Solar=8.1%
				Wind=45.0%		Wind=7.9%
			Renewable	Heat=86.2%	Renewable	Heat=31.2%
				Heat=64.3%		Heat=23.3%
Onshore-Offshore	22%	Before Renewable energy renovation	Thermal	Solar= 11.7%	Thermal	Solar= 13.2%
				Wind= 10.5%		Wind= 11.1%
		After Renewable energy renovation	Thermal	Solar= 14.4%	Thermal	Solar= 12.2%
				Wind= 13.4%		Wind=11.0%

This close relationship suggests that the merit order (as used in the simulation) generally holds, especially at average conditions. Though there is deviation from the historical prices, the shapes of the bid curves should remain the same, meaning our estimations of net price change from the simulation should remain accurate. Assuming that increased solar generation does not affect the frequency of these violations of merit order, the simulation output should generally underestimate the magnitude of net price change, since the calculated prices skew towards less extreme price spikes as compared to the actual prices.

Table 4. Mean supply of resources by season in MW for PV-HPF

Seasons	**Coal**	**Gas**	**Hydro**	**Nuclear**	**Oil**	**Refuse**	**Solar**	**Wind**
Fall	13479.75	152704.2	22030.76	96277.12	758.9597	18860.66	242.5975	3965.202
Winter	34411.78	134773.2	25056.74	108011.7	4508.19	18963.97	123.934	3907.812
Spring	14614.7	147656.6	28484.43	90669.28	590.3566	17944.67	297.3843	3198.813
Summer	20529.07	207226.5	18501.92	105771.7	2866.21	19437.71	399.6607	2289.614
Total	20535.79	161104.7	23480.92	100068.4	2144.492	18800.74	268.4474	3329.347

6 Conclusion

By simulating the direct effect of increased solar supply on ISO day-ahead electricity market with PV and HPF, the research has created estimations of the effects of different levels of additional solar on the market clearing price, as varying by the level of demand and share of supply provided by natural green energy. These have shown that that reductions in price are greatest when the percentage share of natural gas and level of demand are very high, due to the steepness of the rightmost side of the bid curve which is accessed under these conditions. Regressing the effect of each type of generation in the market on historical clearing prices provided insight on the ordering of these resources in the merit order, as well as on their relative marginal impacts on the clearing price. Though solar and wind share of supply in world is currently still small, providing only about 60% of supply on average, this is set to change. State-sponsored programs, federal subsidies, tax credits, and falling technology costs have made solar one of the fastest growing resources in the world at a time when reducing emissions from the power sector is more important than ever. With more than 4,000 MW of proposed solar projects currently under consideration by ISO, such savings in energy cost for the grid are soon to come. Their markets manage 60% of the nation’s electricity with the objective of balancing supply and demand for the entire system by allowing individual generators to submit bids detailing the quantity and price at which their resource can supply to the market. Solar energy is a rapidly growing resource, already providing 4.5% of electricity in the US and projected to supply up to 35% by 2050. Relying only on the strength of the solar to power its electricity-generating turbines, solar power has no marginal fuel costs. While there are still operational and maintenance costs, the lack of marginal fuel costs makes solar power highly competitive at the margin with other more established types of generation, such as coal, natural gas, hydropower, and nuclear. The modified energy model has a good agreement in energy amount and energy pattern with the actual metered HPF data. On the other hand, the default model’s predictions were far from the actual metered HPF data. For renewability, the simulated renewable energy consumption with modified inputs is 3.9% below of actual metered renewable data while the default model’s prediction was more than 52% below actual renewable use. Using PV-HPF hybrid model indices to represent how well a simulated model describes the variability in the measured data; the modified model has achieved accurate renewability results; with a Solar of 10.99 % and Wind of 9.90%, while the hybrid model has a solar of 57.16% and a Wind of 57.20% in renewable energy comparison.

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